EXPLORATION OF BIOMEDICAL AND PHOTOCATALYTIC PROPERTIES OF TRANSITION METAL OXIDE NANOCOMPOSITES

SYNOPSIS

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1. Introduction

The term composite is not new, a number of composites are known for their improved physical and chemical nature compared to pure material. Specifically, metal oxide nanocomposites are very important in having a multiphase solid material system. Metal oxide nano-composites are important for pharmaceuticals, biomedical, and photocatalytic applications, etc. The technology involves the manipulation of material/elements at the atomic or molecular level known as nanotechnology. Prof. Norio Taniguchi first inaugurated the concept of nanotechnology in 1974 with the multifaceted discipline covering research and technology from chemistry, physics, biology, medicine, and engineering. Nanotechnology generally involves the tailoring of material at a nanoscale. Besides nanoparticles, nano-composite is a multiphase solid material where one of the phases has dimensions of less than 100 nm. Composite materials are the future of any kind of structural design. The multiphase nano-composite materials are used in antibacterial, catalysts, sensors, and various other applications due to their high specific surface area, uniform particle size, surface morphology, and energy band gaps, etc. Various methods given for the synthesis of the nanocomposite can be classified into physical, chemical, and biological or green approaches (Khan et al., 2018; Mathur et al., 2018). However, the physical and chemical methods have been found to be very expensive, toxic, and can have bad effects on human health and the environment. Thus, the synthesis using green and biological methods is currently preferred for antibacterial, antioxidant, and photocatalytic applications (Zhang et al., 2016).

1.1. Nanoparticles

Nanoparticles are particles with dimensions on the nanometer scale (typically ranging from 1 to 100 nanometers) and exhibit unique properties compared to their bulk counterparts. These properties arise due to their small size and high surface-to-volume ratio, which can lead to enhanced surface reactivity and other distinctive characteristics. Some key properties of nanoparticles such as size-dependent properties, quantum effects, optical properties, adsorbents, fuel cells, catalytic activity, magnetic properties, drug delivery, sensors, multi-functionality, biomedical and environmental applications (Kumar et al., 2020; Al-Jawhari, Bin-Thiyab & Elbialy, 2022). The properties of nanoparticles can vary based on various factors such as their composition, size, shape, surface functionalization, and the surrounding environment. These unique properties have led to a wide range of applications in various scientific, industrial, and

technological fields. A few examples of commonly used metal oxide nanoparticles along with their applications:

Zinc is a transition metal of the 3d series with atomic number 30 and the most abundant element in the earth's crust. Zinc possesses two types of crystalline structure (Wurtzite and zinc blende) but mainly shows a wurtzite structure (Guo et al., 2002). Zinc metal is less costly and its nanoparticles have shown properties such as antimicrobial, photocatalytic, drug delivery, and anti-oxidant applications, etc. Zinc oxide nanoparticles are rod, star, and isomeric-like forms, mainly present as clusters.

The copper is a 3d-metal with atomic number 29 and pure copper occurs rarely in nature. Copper oxide nanoparticles are monoclinic in nature. Copper oxide nanoparticles are used as catalysts, anti-oxidants, drug delivery, anti-cancer, and pharmaceuticals field (Knetsch & Koole, 2011). Copper oxide nanoparticles play an important role in the industrial field's use including gas sensors, catalytic processes, and solar cell high-temperature semiconductors (Nations et al., 2015). Copper oxide nanoparticles are highly valuable in antibacterial activity and possess very high surface area and genotoxic effects of copper oxide nanoparticles in neurocell cultures (Perreault et al., 2012).

Nickel is a transition metal with atomic number 28 and Nickel oxide nanoparticles as potential antioxidant activity. It is electrically conductive and hence used for several applications. Nickel nanoparticles are available as nanofluid and in passivated, high-purity, ultra-high purity, coated, and dispersed forms. Nickel oxide (NiO) has in recent times attracted the attention of scientists worldwide for various technological applications including anti-ferromagnetic materials (Krishnakumar et al., 2007). Electrode materials for lithium-ion batteries (Ni, Li & Yang, 2012) and electrochemical supercapacitors (Zhao, Liu & Zhang, 2017). Being a wide band gap (3.6-4.0 eV) p-type semiconductor, it is extensively applied in many fields as adsorbents, solar and fuel cells, photocatalytic agents, gas sensors, and magnetic and antibacterial materials.

Cobalt is a chemical transition element with the symbol Co and with atomic number 27. Cobalt oxide (Co_3O_4) powder has a wide range of applications in various fields of industry including anode material for rechargeable Li-ion batteries, catalysts, gas sensors, and magnetic materials (Koinuma, Hirae & Matsumoto, 1998). Cobalt nanoparticles have various applications due to their high resistance to corrosion as well as oxidation and have potential applications in day-to-day life (Chen, Liu & Sun, 2004).

1.2. Nanocomposites

Metal oxide nanocomposites are materials that combine metal oxide nanoparticles with other substances to create hybrid structures with enhanced or tailored properties. These nanocomposites can offer synergistic effects by incorporating the unique properties of both the metal oxide nanoparticles and the matrix material. Some examples of metal oxide nanocomposites such as polymer-metal oxide, metal-metal oxide, carbon-metal oxide, and metal oxide-nanotube nanocomposites, etc. The properties and applications of metal oxide nanocomposites depend on factors such as the type of metal oxide, matrix material, synthesis methods, and interactions between the components. These nanocomposites have the potential to address challenges and create new opportunities in fields such as electronics, energy storage, catalysis, biomedical applications, and materials science (Elemike et al., 2019). A metal nanocomposite is a mixture of different metals with different phases. Nanocomposite materials are very important due to their multifunctional properties and capabilities.

Green synthesis of metal oxide nanocomposites is a sustainable and environmentally friendly approach to synthesizing nanomaterials with a wide range of applications (Botha et al., 2019). It involves the use of natural sources such as plant extracts, microorganisms, and other bio-based materials as reducing/stabilizing agents to synthesize metal oxide nanoparticles and incorporate them into nanocomposite structures. Unlike traditional methods that often rely on harsh chemicals and high-energy processes, green synthesis aims to minimize the use of harmful substances and reduce energy consumption, thereby decreasing the overall environmental impact of nanomaterial production. This approach also offers the advantage of producing nanocomposites with controlled sizes, shapes, and properties. During the green synthesis process, the bioactive compounds present in the natural sources play a crucial role in reducing metal precursors to form nanoparticles and controlling their growth. These compounds can also aid in the stabilization and dispersion of the nanoparticles within a matrix, leading to the formation of nanocomposites. Green-synthesized metal oxide nanocomposites have found applications in various fields, including catalysis, sensing, drug delivery, environmental remediation, energy storage, and more (Elemike et al., 2019). The use of biocompatible and sustainable materials in their production makes these nanocomposites particularly attractive for biomedical and eco-friendly technologies. Overall, the green synthesis of metal oxide nanocomposites represents a promising avenue for advancing nanomaterial research while prioritizing ecological

responsibility and minimizing the negative impacts on human health and the environment. This research mainly focused on improvement in the effectiveness of different metal oxide nanocomposites for biomedical and photocatalytic applications.

1.3. Methods of Synthesis

Synthesizing metal oxide nanocomposites involves combining metal oxide nanoparticles with other materials, such as polymers, metals, carbon-based materials, or other nanoparticles, to create hybrid materials with enhanced properties. Various methods for the synthesis of metal oxide nano-composites are physical, chemical, and biological or green methods. The physical and chemical methods are costly, toxic, and time-consuming but the biological or green method is cost-effective, non-toxic, and eco-friendly, and researchers have shifted towards green synthesis. The different methods being used for the synthesis of nanomaterials are chemical deposition method, hydrothermal synthesis, sol-gel method, vapor deposition method, and microwave synthesis. But the microwave-assisted green synthesis approach is fast, easy, cost-effective, and eco-friendly in nature (Elemike et al., 2019; Botha et al., 2019). Nanocomposites made by green synthesis are superior to those manufactured with physical and chemical methods. Green synthesis eliminates the use of expensive chemicals, consumes less energy, and generates environmentally friendly products and byproducts.

Green synthesis refers to the environmentally friendly and sustainable method used to produce various materials, including nanoparticles, nanocomposites, and other nanomaterials. Green synthesis aims to minimize the use of hazardous chemicals, energy consumption, and waste production while utilizing renewable resources and benign reaction conditions. This approach aligns with the principles of green chemistry and is of increasing importance for reducing the environmental impact of nanomaterial production. The green methods for nanocomposite synthesis using plants or plant extracts have been suggested as possible environmentally friendly alternatives to physical and chemical methods.

The plant *Ipomoea carnea* is called pink morning glory and grows like a forest. The plant shown in **Fig. 1A** has heart-shaped leaves that are green in color and about 15-23 cm in length. This genus belongs to the family of Convolvulaceae and it can be easily grown from seeds. This plant is very common and found all over India it is also called as besharam/behaya tree because of its unlimited spreading (Daniel et al., 2014). This plant

possesses antibacterial, antioxidant, anticancer, anti-inflammatory, anti-fungal, and wound-healing activities (Khatiwora et al., 2012).

This is an herbaceous annual plant in the dayflower family. It is commonly known as day flowers because they bloom for only one day **(Fig. 1B)**. The genus belongs to the family Commelinaceae. This is also called a Himalayan wild food plant and in the local language, they are called Chura. *Commelina benghalensis* plant has various medicinal uses. This plant possesses antibacterial, antioxidant, and anti-inflammatory activities.

(A) (B)

Figure 1: *Ipomoea carnea* (A) and *Commelina benghalensis* (B)

2. Literature Review

In order to understand the concept of synthesis, characterization, and applications of copper, zinc, nickel, and cobalt oxide nanocomposites, a brief review of the literature has been presented in the following paragraphs.

2.1. Cu/ZnO Nanocomposites

Pal et al. (2015), reported the synthesis of three distinct nanocomposites Cu-ZnO, Cu-Cu_2O-ZnO, and Cu_2O-ZnO by considering the Surface Plasmon Resonance (SPR) effect of Cu in the context of photocatalysis. Additionally, the incorporation of ZnO in these nanocomposites introduced a wide band gap barrier that extended into the visible spectrum. Of particular interest, the Cu-Cu_2O-ZnO nanocomposite exhibited the highest level of photocatalytic activity when compared to the other two composites. This finding underscores the significance of the unique combination of Cu, Cu_2O, and ZnO in enhancing the overall photocatalytic performance.

Chang et al. (2016), successfully synthesized a novel Cu/ZnO core/shell nanostructure, comprised of Cu nanoparticles with an average diameter of 44.4 ± 4.3 nm, enveloped by a finely tuned layer of ZnO measuring 4.8 ± 0.5 nm in thickness. The remarkable result of their work was the efficient photocatalytic performance of these Cu/ZnO core/shell nanomaterials. Notably, these nanomaterials displayed the ability to degrade the pollutant methylene blue, a capability that was notably absent in pure copper nanoparticles. These findings highlighted the immense potential of Cu/ZnO core/shell heterostructures as a promising and effective solution for catalyzing the degradation of pollutants through photocatalysis.

Dinesh et al. (2017) employed a sol-gel technique, catalyzed by 2,3-dihydroxy succinic acid, to fabricate composite materials composed of Cu and ZnO. The outcomes of their experimentation revealed the presence of a wurtzite phase in the resulting Cu/ZnO nanoparticles, with the size of the crystalline structures ranging from 15.86 to 24.25 nm depending on the specific annealing temperature utilized. This particular characteristic underscores the considerable potential of Cu/ZnO as a highly promising and exceptional material for effectively treating wastewater, especially in scenarios involving elevated dye concentrations.

Medina-Ramirez et al. (2019) highlighted the significance of Cu@ZnO nanocomposite as a notable material category with versatile applications encompassing catalysts, photocatalysts, optoelectronic devices, and antimicrobial agents because of its high redox activity. This study specifically investigated the antibacterial effectiveness of Cu@ZnO composites, subjecting them to evaluation against *E. coli* and *S. aureus* bacteria.

Manjari et al. (2020) presented an environmentally friendly approach to produce a nanocomposite composed of silver-copper-zinc oxide (Ag-Cu@ZnO) by utilizing extracts from *Acacia caesia* flowers. The resulting Ag-Cu@ZnO nanocomposite exhibited superior catalytic performance compared to individual metal nanoparticles in the conversion of 4-nitrophenol to 4-aminophenol. Additionally, it displayed impressive efficiency, with a 99 % degradation rate for Rhodamine B and Congo red dyes over four successive cycles. This work underscores the potential of the synthesized nanocomposite for effective and sustainable catalytic and degradation applications.

Pathania et al. (2021) employed an uncomplicated, efficient, and environmentally friendly technique to produce nano heterojunction particles of Cu-ZnO by using leaf extracts from *Melia azedarach*. The effectiveness of the resultant material was evaluated

in its capacity as a photocatalyst, specifically for breaking down chlorpyriphos pesticide present in simulated wastewater. Notably, the highest level of photo-degradation (91 %) of the pesticides occurred at a pH of 6.0. This study highlights the potential of the synthesized material for efficient and eco-friendly remediation of contaminated water sources.

Iqbal et al. (2022) successfully synthesized a nanocomposite of Cu-doped ZnO, incorporating polyacrylic acid (PAA) microgel to tackle the degradation of a colored pollutant using sunlight. The process involved doping ZnO nanostructures with varying amounts of copper (ranging from 1 to 20 %) through the co-precipitation technique. This synthesized material was used to enhance its photocatalytic degradation under sunlight.

2.2. Cu/NiO Nanocomposites

The research conducted by Kolvandi and Sheibani (2015) investigated the synthesis of Cu-NiO nanocomposite powder through a mechanochemical reaction. The study revealed that the resulting product exhibited a crystallite size of 92 nm for the copper component. Throughout the reaction process, the formation of intermediate phases, namely Cu_2O and a solid solution of Cu (Ni), was observed. Additionally, the ultrafine Cu-NiO composite powder had a relatively agglomerated structure.

Vennila, Yoo & Kim (2017) utilized a chemical phase technique to produce a Ni-Co/Fe_3O_4 nanocomposite. The nanocomposite's morphological characteristics revealed flower-like nanostructures with tightly interlaced nanosheets for Cu-Co and its composite with Fe_3O_4. The Ni-Co/Fe_3O_4 nanocomposite demonstrated swift responsiveness for non-enzymatic glucose detection. The resulting amperometric signals displayed a linear correlation with glucose concentration in the range of 1 μM to 11 mM. Notably, this system exhibited an impressively low detection limit of 0.19 μM and a remarkable sensitivity of 2171 $\mu A/mM.cm^2$. The produced sensor was successfully applied to real-time glucose detection in human serum samples, showcasing commendable recovery rates. Moreover, it displayed exceptional performance attributes encompassing selectivity, dependability, accurate measurements, and reproducibility. These findings underline the potential utility of the synthesized catalysts in creating highly sensitive and selective enzyme-free glucose sensors for various practical applications.

Klochko et al. (2018) showed research on a high-energy-gap inorganic metal oxide heterojunction, p-NiO/n-ZnO which was synthesized through two low-temperature solution growth methods. Through an examination of the current-voltage characteristics

in the absence of light and the time-dependent response curves of both NiO films and the resulting NiO/ZnO heterostructures, the study highlighted the potential of these materials for efficient ultraviolet (UV) photodetection applications.

Vivek et al. (2020) studied the hydrothermal synthesis of copper and nickel bimetallic samples in three distinct weight ratios: 25:75, 50:50, and 75:25. Among these variations, the 75:25 ratio exhibited excellent catalytic activity and effective recyclability when employed in the reduction of 4-nitrophenol. This particular ratio had a rate constant of 4.89×10^{-3} s^{-1}, which was three times bigger than the rate constant of pure CuO. The research underscores the importance of concentration-dependent phase formation in bimetallic structures during oxidation, showcasing its direct influence on catalytic performance.

Bashir et al. (2021) used the co-precipitation method to synthesize NiO nanostructures, which were subsequently incorporated onto a reduced graphene oxide (rGO) surface using ultrasonication. The introduction of doping and the formation of the composite were observed to significantly augment the photodegradation capability of the NiO nanostructure. Notably, the rate constant for the composite containing Cu-doped NiO nanostructure and rGO displayed a remarkable 4.4-fold increase compared to the original pristine NiO nanostructure. This enhancement was attributed to the transfer of electrons to copper ions and the reduced graphene surface, thereby facilitating improved photocatalytic activity.

Gnanamoorthy et al. (2022) employed a hydrothermal technique to synthesize $CuNiO_2$ and $CuNiO_2$/rGO nanocomposites for use in photocatalytic studies. Various compositions of $CuNiO_2$ and $CuNiO_2$/rGO (25/75), (50/50), and (75/25) were examined for their photocatalytic efficiency under visible light, revealing that the $CuNiO_2$/rGO (50/50) composite exhibited the highest performance. The investigation further encompassed a comprehensive analysis of the $CuNiO_2$ and $CuNiO_2$/rGO (25/75), (50/50), and (75/25) nanocomposites using techniques such as XRD, FT-IR, DRS UV-Visible spectroscopy, Raman spectroscopy, as well as FESEM and HRTEM examinations. The results of these analyses were not only well-defined but also yielded satisfactory outcomes. This result shows a strong impetus for the exploration of future environmental applications in this field.

2.3. Cu/Co_3O_4 Nanocomposites

Madhu et al. (2015) have synthesized *Pongam* seed shells-derived activated carbon and cobalt oxide (~ 2-10 nm) nanocomposite (PSAC/Co_3O_4). This composite

was effectively utilized in two distinct applications: high-performance nonenzymatic glucose sensors and supercapacitors. The fabricated glucose sensor exhibited an exceptional sensitivity of 34.2 mA mM^{-1} cm^{-2}, along with an impressively low detection limit of 21 nM. This sensor also demonstrated remarkable long-term stability. These findings underscore the superior suitability of PSAC/Co_3O_4 for non-enzymatic glucose sensors and supercapacitor applications. These synthesized materials as highly promising for practical use in industrial applications.

Dinesh et al. (2017) synthesized nanocomposite of reduced graphene oxide (RGO) and cobalt oxide (Co_3O_4) by using a simple *in situ* electrochemical process. These nanocomposites exhibited remarkable potential for detecting trace amounts of serotonin in the presence of interfering substances like ascorbic acid and dopamine. Interestingly, the oxidation peak current (I_p) of serotonin observed at the electrode modified with GCE/RGO/Co_3O_4 was 4.1 times higher than that of GCE/RGO, and 2.4 times higher compared to GCE/Co_3O_4. A comparison of sensor efficiency with previous work clearly shows the superiority of the developed sensor. Furthermore, the sensors can detect serotonin *in vitro* directly from diluted blood serum samples.

Bakhsh et al. (2021) used a simple way to develop the tin oxide-cobalt oxide nanocatalyst, which formed in spherical particles with an average diameter of 30 nm. Tin oxide-cobalt oxide and Alg@tin oxide-cobalt oxide nanocatalysts were investigated for the catalytic reduction of 4-nitrophenol, congo red, methyl orange, methylene blue (MB), and potassium ferricyanide in the presence of sodium borohydride. These findings revealed that the Tin oxide-cobalt oxide and Alg@tin oxide-cobalt oxide nanocatalysts reduced MB in less time (2.0 and 4.0 min) than other dyes. The rate constants for MB reduction were calculated and found to be 1.5714 min^{-1} for tin oxide-cobalt oxide nanocatalyst and 0.6033 min^{-1} for Alg@tin oxide-cobalt oxide nanocatalyst, respectively.

Yadav et al. (2022) successfully synthesized nickel oxide (NiO) and cobalt oxide (Co_3O_4) nanocomposites through a simple two-step wet-chemical method utilizing L-ascorbic acid. The L-ascorbic acid has been used as a stabilizing agent/capping agent. The team thoroughly examined the physical and chemical characteristics of the fabricated nanocomposites employing various spectroscopic techniques, including X-ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), X-ray photoelectron spectroscopy (XPS), and Fourier-transform infrared (FT-IR) spectroscopy. The outcomes of these analyses unveiled that the photocatalytic degradation capability of the developed nanocomposites was probed

against methylene blue (MB) dye. Remarkably, the synthesized nanocomposite exhibited an impressive performance, leading to the degradation of 89.88 % of the MB dye within 360 minutes under sunlight exposure.

3. Research Gap Identification

Metal oxide nanocomposites offer a wide range of applications due to their tunable properties and enhanced functionalities. They contribute to advancements in various fields, including nanotechnology, materials science, energy, healthcare, and environmental science. However, several research gaps and challenges still exist in this area. But the most significant key research gap is the need for innovative synthesis techniques, enhancement in biomedical and photocatalytic applications that allow precise control over nanoparticle properties, improving stability, durability, multi-functionality, reducing toxicity and environmental impact. Addressing these gaps will further drive the development and application of metal oxide nanocomposites in innovative and impactful ways.

Although there are various methods for the synthesis of different metal oxide nanocomposites but the microwave-assisted green method using medicinal leaf extracts with different ratios of d-block (3d-series) metal precursors is the most important one and has not been explored. Furthermore, the nanocomposites with the above-mentioned plants (*Ipomoea carnea* and *Commelina benghalensis*) are another innovative idea and few works reported with these plants for bimetallic oxide nanocomposites. Also, it will be innovative to explore microwave-assisted nanocomposites in photocatalytic, antioxidant, and antibacterial applications.

4. Objectives

The main objectives of the above discussion are as follows:

- To synthesize different metal oxide nanocomposites (Cu/ZnO, Cu/NiO, and Cu/Co_3O_4) by using microwave-assisted green method.
- To characterize the synthesized nanocomposites by employing various spectroscopic techniques such as XRD (X-ray powder diffraction), SEM (Scanning electron microscopy), EDX (Energy Dispersive X-ray Analysis), TEM (Transmission electron microscopy), FTIR (Fourier-transform infrared spectroscopy) and UV-Visible spectroscopy.

- To explore the photocatalytic, antioxidant, and antibacterial activities of the synthesized nanocomposites.

5. Proposed Methodology

From the literature survey, the number of physical, chemical, and biological methods (Clapsaddle et al., 2004; Patelli et al., 2019; Yadav & Kim, 2016; Nagarani et al., 2018) are studied. In the present study, we focused on a green method of synthesis, (Kannan et al., 2021; Lin & Chen, 2014; Elemike, Onwudiwe & Singh, 2020; Bhavyasree & Xavier, 2020) which involves the use of medicinal plant extracts of *Ipomoea carnea* and *Commelina benghalensis* for the synthesis of bimetallic oxide nanocomposites using microwave-assisted green technique.

5.1. Materials

Copper (II) acetate monohydrate, Zinc acetate dihydrate, Cobalt (II) acetate tetrahydrate,-Nickel (II) nitrate hexahydrate, sodium hydroxide (NaOH), methyl orange, methylene blue, malachite green, Congo red, 2,2-diphenyl-2-picryl hydrazyl hydrate (DPPH) and 99 % ethanol will be used. Bacteria *Bacillus sub-tilis* (MTCC 441), *Staphylococcus aureus* (MTCC 737) and *Escherichia coli* (MTCC 739), medicinal plant leaves of *Ipomoea carnea*, and *Commelina benghalensis* will be collected from nearby areas of Career Point University, Hamirpur for the preparation of leaf extract.

5.2. Methods

5.2.1. Preparation of Leaf Extract

Ipomoea carnea and *Commelina benghalensis* leaves will be collected and washed with regular tap water before being rinsed with distilled water to remove contaminants. After that, the shade was dried in an oven at 60 °C for 48 hours. The dried leaves will next be crushed with a mortar pestle and refluxed in a predetermined volume of water at a specific temperature. The refluxed extract will be filtered using Whatmann filter paper and refrigerated.

5.2.2. Synthesis of Nanocomposites

Metal precursor solutions of different concentrations will be prepared in the distilled water. A fixed volume of different solutions will be taken in a beaker and the fixed volume of leaf extract and base will be added by dropwise addition with constant stirring for some time. After that deep internal homogenously, heat up the reaction

mixture in the microwave. Finally, the prepared nano-materials were washed with distilled water and ethanol and then dried in a vacuum oven at 80-100 °C for 24 hours.

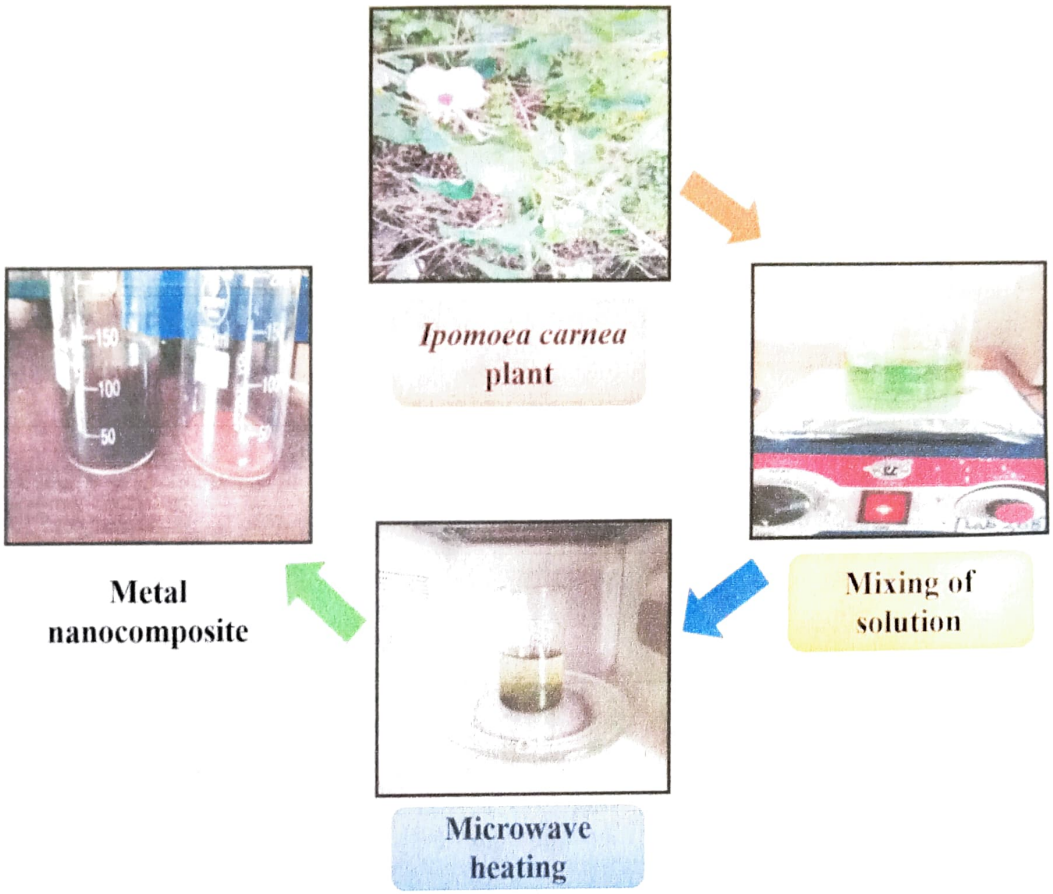

Figure 2: Microwave-assisted green method to synthesize metal oxide nanocomposites

5.3. Characterization

The synthesized nanocomposite materials will be characterized by XRD, SEM, EDAX, TEM, FTIR, and UV-visible spectroscopy for the analysis of crystallite size, phase identifications, crystalline nature, morphology, elemental composition, functional groups, and particle size.

5.4. Applications

5.4.1. Photocatalytic Activity

In this study, the synthesized nanocomposites be used for the degradation of different dye solutions. The photocatalytic degradation of the dyes (methyl orange, methylene blue, malachite green, congo red, etc.) will be examined by measuring the absorbance by using a UV-visible spectrophotometer. The procedure will be followed as given by (Sharma et al., 2020; Chang et al., 2016).

5.4.2. Antibacterial Activity

The synthesized nanocomposite materials used for the anti-bacterial activities (Mohammadi-Aloucheh et al., 2018) by investigating their zone of inhibition against *Staphylococcus aureus* (MTCC 737), *Escherichia coli* (MTCC 739) and *Bacillus subtilis* (MTCC 441). The procedure will be followed as given by (Sharma et al., 2020; Sharma et al., 2021; Mohammadi-Aloucheh et al., 2018).

5.4.3. Antioxidant Activity

The synthesized nanocomposite materials used for the anti-oxidant activity (Sushma et al., 2016) by investigating the radical scavenging against stable 2,2-diphenyl-2-picryl hydrazyl hydrate (DPPH) free radical at different concentrations by using serial dilution. The procedure will be followed as given by (Sushma et al., 2016). The antioxidant activity of the synthesized nanocomposites against free radicals (DPPH) will be examined by measuring the absorbance using a UV-visible spectrophotometer.

6. Thesis Outline

CHAPTER 1 (Introduction)

This chapter will contain a brief introduction regarding NCs, biological methods, plant extract, and NCs of transition metals.

CHAPTER 2 (Literature Review)

This chapter will deal with the literature survey of synthesis, characterization, and eco-friendly applications of metal oxide nanocomposites.

CHAPTER 3 (Materials and Methods)

It contains experimental details on the material used, biological method of synthesis, characterization techniques, and applications of synthesized NCs.

CHAPTER 4 (Results and Discussion)

This chapter will comprise a detailed discussion of the results of the present study which includes the key points and various aspects of synthesis, characterization, and applications of transition metal oxide (Cu/ZnO, Cu/NiO, and Cu/Co_3O_4) NCs.

CHAPTER 5 (Summary and Conclusion)

This chapter will summarize and correlate all the above-mentioned chapters in a lucid manner.

CHAPTER 6 (References)

This chapter will contain all the references cited in the thesis.

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CERTIFICATE
(SYNOPSIS APPROVAL CERTIFICATE)

This is to certify that the Synopsis for Ph.D. Thesis titled, **"EXPLORATION OF BIOMEDICAL AND PHOTOCATALYTIC PROPERTIES OF TRANSITION METAL OXIDE NANOCOMPOSITES",** submitted by **Mr. Ravi Kumar** to the Career Point University, Hamirpur (H.P.), India in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in the Department of **Chemistry**, School of **Basic and Applied Sciences** has been approved by the Research Advisory Committee (RAC) after an Oral Examination of the student on dated 28.06.2022.

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